U.S. DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY CORRELATION OF MAP UNITS 400 300 200 100 100 200 COASTAL PLAIN DEPOSITS QUANTICO MARINE CORPS DEVELOPMENTAND EDUCA > Pliocene CHOPAWAMSIC THRUST FAULT METASEDIMENTARY AND METAVOLCANIC **ROCKS OF THE PIEDMONT INTRUSIVE ROCKS** Garrisonville Estates **DESCRIPTION OF MAP UNITS** Artificial fill—Sandy and gravelly materials in areas filled for construction of roads, highways, bridges, and dams CENOZOIC AND UPPER MESOZOIC DEPOSITS OF THE ATLANTIC COASTAL PLAIN Deposits of Present-day Streams and Valleys Marsh and swamp deposits, undivided (Holocene)—Marsh deposits consist of soft mud and muddy sand, medium-gray to dark-gray; may include grayish-brown peat or peaty sand and mud; thickness generally less than 20 ft (6 m). Deposited at or near sea level in tidewater parts of Aquia Creek; may be vegetated by rushes and other grasslike plants. Swamp deposits consist of brownish-gray and brownish-black mud, muddy sand, and muck containing abundant decaying leaf and stem material and trunks of trees. Unit thickly vegetated by shrubs and trees; occurs as a thin veneer less than 10 ft (3 m) thick directly overlying alluvial fill of stream valleys Alluvium (Holocene and Pleistocene)—Fine to coarse gravelly sand and sandy gravel, silt, and clay; unit is light gray to medium gray and vellowish grav: clasts consist mainly of vein quartz, quartzite, and other metamorphic rocks. Deposited mainly in channel, point-bar, and flood plain environments; grades into colluvium along steeper valley walls at margins of unit. Unit is mostly Holocene but, locally, may include lowlying Pleistocene terrace deposits. Thickness along major streams is as much as 50 ft (15 m) Sedgefield Member of Tabb Formation (upper Pleistocene)—Pebbly to bouldery, fine to coarse, crossbedded sand grading upward to sandy and clayey silt; unit is pale gray to medium gray and yellowish gray. Constitutes surficial deposits of low-level terraces (altitude 25 to 33 ft (8–10 m)) bordering Aquia Creek. Thickness is as much as 40 ft (12 m) Shirley Formation (middle Pleistocene)—Fine to coarse sand, in part pebbly and bouldery, light-gray to medium-gray and pale-yellowish-gray; grades upward to silty fine sand and sandy silt, pale-gray to pinkishgray. Constitutes surficial deposits of terraces (altitude 40 to 50 ft (12–15 m)) in the Aquia Creek valley. Thickness is 20 to 40 ft (6–12 m) Marine, Marginal-marine, and Fluvial-deltaic Deposits Sand and gravel (Pliocene)—Interbedded yellowish-orange and reddishbrown gravelly sand, sandy gravel, and fine to coarse sand, very poorly sorted to moderately well-sorted, commonly trough crossbedded; includes lesser amounts of clay and silt in thin to medium beds. Unit is as much as 35 ft (11 m) thick. Occurs mainly in southern part of map DUMFRIES FAULT ZONE area as small outliers that cap the relatively undissected upland between Accokeek Creek and Potomac Creek. Unit commonly overlies fine sand of the Calvert Formation but extends westward across the Fall Zone and into the Piedmont as high-level terrace deposits that directly overlie crystalline rocks. To the south and east of map area, unit composes extensive sheets of fluvial-deltaic sand and gravel constituting surficial deposits of the Coastal Plain upland. These strata overlie and interfinger(?) with thin nearshore-shelf deposits of the Pliocene Yorktown Formation outside this quadrangle (Mixon and others, 2000) Sand and gravel (Miocene)—Fine to coarse gravelly sand, sandy gravel, silt, and kaolinitic clay; unit is gray to light yellowish gray; commonly weathers to dark yellowish orange, yellowish and reddish brown, and dark red. Pebbles and cobbles are mainly quartz, quartzite, and crystalline rock and are commonly well rounded and deeply etched; crumbly in part. Unit commonly caps interfluve areas west of the Thornburg scarp (Mixon and others, 2000) and constitutes the thin Coastal Plain outliers capping higher hills in easternmost Piedmont where gravelly deposits directly overlie crystalline rocks. Locally as much as 15 ft (5 m) of fine marine sands, thought to be erosional remnants of the Calvert Formation, are present between unit Tms and the crystalline rocks. Unit is as much as 35 ft (11 m) thick Calvert Formation (middle and lower Miocene)—Chiefly fine to very fine quartzose sand, variably silty and clayey, interbedded with diatomaceous silty clay and clayey silt; thick-bedded to very thick INTERSTATE HIGHWAY 95 bedded or massive. In updip areas, basal 4 to 5 ft (1–2 m) of unit is very poorly sorted, very fine to coarse clayey sand containing abundant granules and fine pebbles of quartz and phosphate; discontinuous, horizontally bedded clay laminae give distinctive, streaked appearance to sandy outcrops. Unweathered Calvert is medium olive gray to dark olive gray, grayish olive, and dark greenish gray; lower clayey part of unit weathers to a red-mottled light gray; upper sandy part weathers to a pale yellow, pale yellowish orange, or white. In the map area, the Calvert successively overlies, from southeast to northwest, the Nanjemoy, Aquia, and Potomac Formations; thus, the uneven lower contact is a major erosional unconformity. Near Sheltons Shop and Mountain View, the Calvert beds lap across the Potomac Formation onto crystalline rocks of the outer Piedmont including the Garrisonville Mafic Complex (OZgm) and the Richland Run (Opg) and Potomac Creek (PzZgn) plutons. Thickness ranges from 50 ft (15 m) or more in the eastern part of the map area to a feather edge at the Piedmont overlap. Age of unit based on studies of planktonic foraminifera and diatom and molluscan assemblages (Akers, 1972; Andrews, 1988) FALL HILL FAULT Pamunkey Group (Nanjemoy Formation, Marlboro Clay, and Aquia Over much of the Coastal Plain part of the map area, a thin to thick blanket of glauconitic sand and silt of marine origin unconformably overlies the eroded, irregular surface of the Lower Cretaceous Potomac Formation. These glauconitic strata were named the Pamunkey Formation by N.H. Darton (1891) for the extensive exposures along the Pamunkey River to the south of the map area in Caroline, Hanover, and King William Counties, Virginia. Subsequently, Clark and Martin (1901) raised the Pamunkey Formation to group status and divided it into the Aquia Formation, named for Aquia Creek in Stafford County, Virginia, and the Nanjemoy Formation, named for Nanjemoy Creek in Base from U.S. Geological Survey, 1994 Charles County, Maryland. These streams are tributaries of the 2,500-meter grid ticks based on Virginia coordinate system, north Potomac River. Clark and Martin (1901, p. 65) also recognized a thin but laterally very extensive pink to red clay, referred to informally as the 1,000-meter Universal Transverse Mercator grid, zone 18 Marlboro Clay, which separates the Aquia and Nanjemoy glauconitic CONTOUR INTERVAL 10 FEET NATIONAL GEODETIC VERTICAL DATUM OF 1929 Nanjemoy Formation (lower Eocene)—Glauconitic quartz sand, very fine to fine, very clayey and silty, micaceous, contains fairly abundant small concretions of iron sulfide; unit is commonly intensely bioturbated, shelly in part; includes a few thin, discontinuous beds of limestone. Fresh exposures are dark olive gray, greenish gray, and olive black; weathers yellowish brown. Only the lower member (Potapaco) of the Nanjemov (Ward, 1985; Mixon and others, 2000) is present in the southeastern corner of the map area where poorly exposed outcrops occur in small, deeply incised stream valleys south of Brooke, Va. The Nanjemoy unconformably overlies the Marlboro Clay and, locally, where the Marlboro has been removed by erosion, the Aquia Formation. Maximum formation thickness in the map area is only about 30 ft (9 m). The updip limit of the Nanjemoy Formation is the southeasternmost strand of the Brooke fault zone Tmc | Marlboro Clay (upper Paleocene)—Kaolinitic silty clay and clayey silt, light-gray to dark-gray, light-brown, and pale-red to reddish-brown. Appears massively bedded, but cores and weathered outcrops show laminated to thin-bedded character of unit. Clay is commonly interbedded with lesser amounts of laminated and ripple-cross-laminated fine silt; small scour channels filled with sandy silt occur locally in updip areas. Rare molds of small mollusks, agglutinated foraminifers, a low diversity dinocyst assemblage, and the freshwater alga Pseudoschizaea indicate a brackish-water depositional environment. Gradational contact with underlying Aquia Formation is commonly marked by interbedding, over a 2- to 3-ft (0.5- to 1.0-m)-thick interval, of thin beds of kaolinitic Marlboro Clay and fine sand of the Aquia Formation. Unconformable relation with overlying Nanjemoy Formation indicated by abrupt, 0 10 20 METERS uneven contact and by large, sand-filled burrows extending from base of Nanjemoy downward for 2 to 8 ft (0.6-2.4 m) or more into the Marlboro Clay. Sporomorph data (Frederiksen, 1979) from lower part Potomac Formation of Marlboro indicate a late Paleocene age. The Marlboro Clay is present only in extreme southeastern corner of map area where it is preserved Figure 3.—Sketch of south wall of trench across Fall Hill fault, Falmouth, Va., approximately 2 mi on downthrown side of Brooke fault zone. Thickness ranges from less south of Stafford quadrangle. Modified from Potomac Electric Power Company (1976). Nearby than 1 ft (0.3 m) to about 10 ft (3 m). Unit is shown by red line at top Figure 2.—Trench profile and section across Dumfries fault zone near Stafford, Va. A, Main fault outcrop and borehole data show that the same high-angle reverse and vertical faults shown here, of underlying Aquia Formation surface and shear; B, Episodic reverse faulting, slumping, and sedimentation. The location of this offset top of basement rock by as much as 120 ft. Aquia Formation (upper Paleocene)—Glauconitic quartz sand, fine to section on the map is indicated by the  $^{1}\square$  symbol. 300 300 200 100 100 300 nedium, variably clayey and silty, thick- to very thick bedded or massive, sparsely to abundantly shelly. Fresh exposures are light olive gray to dark olive gray, olive black, and greenish black; weathers to yellowish gray, grayish yellow, grayish orange, and reddish brown. In

the southeastern, downdip part of the map area, the Aquia sand is commonly interbedded with a few thick beds of sandy and shelly limestone; locally, in shelly beds of updip areas, silica replaces calcium carbonate as the cementing material creating a hard, flinty rock. Unconformable contact relations between Aquia Formation and underlying Potomac Formation is commonly marked by fine to coarse pebbles in basal Aquia. Formation thickness ranges from a few feet along the western margin of outcrop to as much as 115 ft (35 m) on the downthrown, eastern side of the Brooke fault zone Potomac Formation (Lower Cretaceous)—Includes three main sediment types. Type I consists of fine to coarse feldspathic quartz sand and sandstone, thick- to very thick bedded, trough crossbedded, poorly

sorted; clay-silt matrix constitutes as much as 40 percent of sediment; commonly contains pebbles and cobbles of vein quartz, quartzite, and other metamorphic rocks. Outcrops are very light gray to medium gray or pinkish gray; fresh core material may be greenish gray or bluish gray. Locally, white to light gray, well-cemented sandstone forms discontinuous low cliffs or rocky outcroppings. Intraformational conglomerates containing pebble-size clasts of clay and silt are common; locally, clay-silt boulders up to 3 ft (1 m) in diameter suggest undercutting and caving of channel walls. Type I sediments are interpreted as channel-lag and channel-bar or point-bar deposits. Type II sediments consist of silty and sandy clay, clayey silt, and clayey fine sand; unit is greenish gray, commonly mottled red or reddish brown; clay minerals are mainly illite and smectite. Commonly forms clay-silt plugs, 3 to 20 ft (1-6 m) thick and 7 to 65 ft (2-20 m) wide, within a dominantly medium to coarse sand sequence; clay plugs are believed to have formed by filling of abandoned stream channels (cutoffs) by fine sediments during flood stages. Coalified stems of plants, as much as 1 ft (30 cm) in diameter, occur locally in types I and II; silicified trunks of large coniferous trees are present, but rare. Type III sediments consist of dark-yellowish-brown to olive-gray, lignitic sandy silt, clay, and silty fine sand and sandstone, flaggy in part. Occurrence as thin to thick beds associated with type I sediments suggests deposition in swales of point bars and (or) swampy areas of flood plains. Types I and III sediments may contain well-preserved leaf and stem impressions of ferns, cycadeoids, conifers, and the angiosperm Ficophyllum (table 1). Thickness of Potomac Formation ranges from a feather edge at western limit of outcrop to about 400 ft (122 m) in the subsurface of the eastern part of the map area. Analysis of pollen (Frederiksen, 1979) and leaves from the Potomac beds in and near the map area indicate an Early Cretaceous (Barremian(?), Aptian, and Albian) age for outcrop and subsurface sections (J.A. Doyle, oral commun., 1971)

## PALEOZOIC AND PROTEROZOIC ROCKS OF THE PIEDMONT

Metasedimentary and Metavolcanic Rocks Lunga Reservoir Formation (Ordovician)—Metadiamictite (metamorphosed sedimentary mélange) consisting of nonstratified, pebbly, micaceous, quartzofeldspathic metagraywacke in which granuleto boulder-size clasts of metasedimentary and meta-igneous rock are supported. Characterized by abundant polycrystalline, granoblastic quartz lumps that are interpreted as clasts; also contains chips and pebbles of gneiss and schist, some of which have internal foliation athwart that of enclosing matrix. North of quadrangle, exposures contain clasts of metamafic rock, including greenstone, thought to be derived from the Chopawamsic Formation (Pavlides, 1989, 1995, 2000). Unit interpreted by Pavlides (1989, 2000) as part of a back-arc

Quartz mylonite and ultramylonite (Ordovician)—Light-gray to medium-gray, very fine grained, thin-layered, quartz-ribbon mylonite. Occurs in Long Branch fault zone as lenses at the base of and within the Quantico Formation. Previously mapped as "quartzite" (Pavlides, 1990, 2000). Protoliths may include both the Quantico Formation and the Chopawamsic Formation Quantico Formation (Upper Ordovician)—Black to medium-gray slate, phyllite, and schist (Oq) and minor interbeds of volcaniclastic rock (Oqv), interpreted by Pavlides (1989, 1990, 2000) and Horton and others

(1989) as part of a successor basin Oq Black to medium-gray slate, phyllite, and schist—In northeastern part of quadrangle, unit is mostly black to medium-gray slate and phyllite, commonly graphitic and pyritic. Beds of fine-grained metagraywacke, a few centimeters to meters thick, are locally intercalated and commonly consists mainly of fine-grained to medium-grained garnetiferous biotitemuscovite schist, staurolite-mica schist, and phyllite; minor diopsidic calc-silicate granofels lenses and kyanite-bearing quartz veins occur locally. Age of Quantico Formation is based on pelecypods from black slates along Powells Creek (Watson and Powell, 1911), northeast of map area in Quantico quadrangle. These fossils, examined by R.S. Bassler of the U.S. National Museum, are "closely related to Cincinnatian forms of Pterinea such as P. demissa Conrad" and, thus, are Ordovician. An important fossil locality in Dale City, Va., has crinoid stems with star-shaped lumens and an actinoceroid cephalopod that indicate an Ordovician or younger age (Pavlides, 1980). Crenulations and kink folds are common. Quartz mylonite and ultramylonite (Omq) occur as discontinuous lenses in vicinity of the Long

Branch fault zone Metamorphosed volcaniclastic rock—Felsic to mafic. Includes etamorphosed felsic to mafic volcaniclastic rock south of Mountain View. Light-gray, crudely layered, strongly cleaved, felsic metatuff near Smith Lake dam occurs as layers up to 20 ft (6 m) thick, interbedded with very light gray metasiltstone and dark-gray slate. Equivalent to "felsic tuff" of Mixon and others (1972) and "felsic volcaniclastic member" of Seiders and Mixon (1981). Zircons from metamorphosed lapilli tuff layer in lower part of Quantico Formation have a SHRIMP (sensitive high-resolution ion microprobe) U-Pb age of 451±6 Ma (Horton and others, 1998), which is compatible with Ordovician-age fossils in the slate (Oq)

Chopawamsic Formation (Ordovician)—Interlayered metavolcanic and metasedimentary rocks interpreted as part of Ordovician volcanic arc terrane (Pavlides, 1981, 1989, 2000; Horton and others, 1998) Interlayered metavolcanic and metasedimentary rocks—Metavolcanic facies, mostly mafic to intermediate, includes amygdular and vesicular flows as well as fragmental volcanic breccias and tuffs. Mafic rocks include fine-grained layered amphibolite, amphibole schist, and chlorite schist. Intermediate rocks include dark-gray to light-greenish-gray, finegrained quartz-amphibole-plagioclase gneiss, which commonly has nematoblastic alignment of amphibole prisms. Felsic interlayers are minor (except where separately mapped as Ocf), fine-grained, light-gray to white, and locally contain crystal phenocrysts of quartz or plagioclase and lithic fragments. Fine-grained, feldspathic schist and phyllite without identifiable fragments are mineralogically and chemically similar to more distinctive volcanic rocks and may be tuffaceous. Schist, metasandstone, and amphibole-free gneiss of probable sedimentary origin occur as interlayers. Includes chloritic phyllonite in Long Branch fault zone Metafelsite—Very light gray to white, fine-grained, layered felsic metavolcanic rock; locally contains phenocrysts of quartz or plagioclase and lithic fragments (mainly lapilli). Occurs in drainages of Potomac Creek and Aquia Creek as interlayers in fine-grained amphibole gneiss of unit Oc. Zircons from a sample at Stop 5C of Pavlides (1976) have a SHRIMP U-Pb age of 454±5 Ma (Horton and others, 1998). Unit includes metamorphosed felsic volcaniclastic rocks; also includes

keratophyre consisting of albite and quartz in fine-grained quartzfeldspar matrix; locally mylonitic in Long Branch fault zone Amphibolite (Ordovician)—Dark-gray, fine-grained, and composed mainly of hornblende and plagioclase; locally garnetiferous; thought to be metamorphosed mafic volcaniclastic rock. Occurs along southeastern flank of Quantico Formation. Similar and possibly equivalent to amphibolites in Chopawamsic Formation. Includes amphibolite from Potomac Creek as described by Pavlides (1980, table 4, sample P-70-51; 1981, table 3, samples 1, 2). Previously mapped as garnetiferous amphibolite (Pavlides, 1976), Ta River Metamorphic Suite (Pavlides, 1980, 1981), and Holly Corner Gneiss (Mixon and others,

Muscovite-biotite granite (Silurian or Ordovician)—Dark-gray granite naving quartz, abundant microcline, and minor sodic plagioclase. Occurs as a small pluton apparently intrusive into both the Garrisonville Mafic Complex (OZgm) and Richland Run pluton (Opg)

Metatonalite of the Richland Run pluton (Ordovician?)—Typically coarse-grained and well-foliated. Composed mainly of plagioclase (26-41 percent), quartz (44-48 percent), lesser amounts of epidote (0-19 percent); accessory minerals include muscovite (2-6 percent), biotite (1-5 percent), chlorite (0-6 percent), and opaque minerals (<2 percent); trace amounts of garnet are rare. Some quartz appears blue. Petrography and chemistry described by Pavlides (1981, table 5, samples 3-5). Locally protomylonitic to mylonitic; also locally intruded by mafic dikes not shown on map. For much of its extent, pluton has intrusive contacts with Garrisonville Mafic Complex and Chopawamsic Formation and thus is no older than Ordovician. Ordovician age inferred from dating of similar plutons in the region (Aleinikoff and Amphibole metagabbro (Ordovician)—Coarse-grained to mediumgrained, melanocratic; massive to foliated and cut by numerous mafic dikes not shown on map. Intrudes Chopawamsic Formation just west of

Mountain View and contains xenoliths of the Chopawamsic (Pavlides, 1976, Stop 5B) Garrisonville Mafic Complex (Ordovician to Neoproterozoic?)—Amphibolite and hornblendite, fine-grained to coarse-grained, massive to foliated. West of this quadrangle, metamorphic alteration is less intense, and metamorphosed enstatite-bearing pyroxenite, websterite, and norite are locally present (Pavlides, 1995, 2000). Interpreted as part of a volcanic arc (Pavlides, 1981, 2000) or a

remnant of oceanic crust (Pavlides, 1989, p. 180) Gneiss of the Potomac Creek pluton (lower Paleozoic or Neoproterozoic?)—Gray, fine-grained to medium-grained, foliated and lineated, biotite-quartz-plagioclase gneiss of tonalitic, dioritic, or granodioritic composition. Includes accessory epidote, sparse garnet, and minor muscovite. Contains thin (<1 cm) granitoid layers concordant with gneissic foliation (Pavlides, 1980, fig. 4), concordant granitoid and pegmatite layers up to 25 ft (8 m) thick, and irregular granitoid masses (Pavlides, 2000, p. 5). Petrography, geochemistry, and geochronology have not been studied; contact relations undetermined due to poor exposure. Previously mapped and described as tonalite gneiss (Pavlides, 1980, pl. 1), granodioritic gneiss (Pavlides, 1995; Pavlides, 2000, p. 5), or diorite gneiss (Pavlides, 1990; Mixon and others, 2000), and inferred to intrude either Ta River Metamorphic Suite (Pavlides, 1980, pl. 1) or Po River Metamorphic Suite of Matta nappe (Pavlides, 2000, p. 5). Exposed in southwestern corner of quadrangle

## **EXPLANATION OF MAP SYMBOLS**

———— Contact—Dotted where concealed

——— Fault—Sense of displacement not known

———— Structure contour—Drawn at the base of the Aquia Formation. Contour interval 10 ft

High-angle fault—Dashed where inferred; dotted where concealed; U, upthrown side; D, downthrown side. Arrows show relative strike-slip

Thrust fault—Sawteeth on upper plate; dashed where inferred; dotted

**Foliation folds**—Showing axial trace, direction of dip of limbs and plunge direction, where known or inferred. Foliation may be parallel to bedding

where concealed

Overturned

and (or) compositional layering Antiform Synform →►80 Antiform

→<sup>75</sup> Synform →20 Dextral or Z-fold PLANAR FEATURES

(May be combined with linear features; some symbols show positions of outcrops measured before flooding by artificial lakes) Strike and dip of bedding

> Strike and dip of compositional layering Strike and dip of cleavage Inclined

⊢ Vertical Strike and dip of joints—Two or more sets shown at point of intersection Vertical

Strike and dip of phyllitic foliation—Includes semi-schistosity and transposition foliation Inclined Vertical

Strike and dip of early schistosity Inclined Vertical Strike and dip of magmatic flow foliation

LINEAR FEATURES

(May be combined with planar features) → 40 Bearing and plunge of inclined late mineral lineation Bearing and plunge of horizontal late mineral lineation

OTHER SYMBOLS

(Provide control for cross section) • U.S. Geological Survey corehole—TD=Total depth, in feet U.S. Geological Survey auger hole

Water well—G, geophysical log; L, lithic log; TD=Total depth, in feet U.S. Geological Survey trench and borehole that exposed Dumfries fault zone near Stafford, Va. Detail in figure 2 Potomac Electric Power Company trench that exposed upper part of Dumfries fault zone Roadcut exposure that showed vertical Cretaceous strata on downthrown side of Dumfries fault zone, Va. Route 630

Outcrops in high roadcut showing Dumfries fault zone Paleocene fossiliferous limestone locality Cretaceous palynomorph locality 

A Radiometric age determination (uranium-lead zircon) for Chopawamsic Formation (Horton and others, 1998) Active quarry (Vulcan Materials Company Stafford quarry)

INTRODUCTION The Stafford 7.5-min quadrangle, comprising approximately 55 square miles (142.5 square kilometers) of northeastern Virginia, is about 40 miles (mi) south of Washington, D.C. The region's main north-south transportation corridor, which connects Washington, D.C., and Richmond, Va., consists of Interstate 95, U.S. Highway 1, and the heavily used CSX and Amtrak railroads. Although the northern and eastern parts of the Stafford quadrangle have undergone extensive suburban development, the remainder of the area is still dominantly rural in character. The town of Stafford is the county seat. The Stafford 7.5-min quadrangle is located in the Fredericksburg 30'x60' quadrangle, where information on the regional stratigraphy and structure is available from Mixon and others' (2000) geologic map and multichapter explanatory text. In addition to straddling the "Fall Zone" boundary between the Appalachian Piedmont and the Atlantic Coastal Plain provinces, this quadrangle contains the best preserved and best studied segment of the Stafford fault system, an important example of late Cenozoic faulting in eastern North America (Mixon and Newell, 1977). This 1:24,000-scale geologic map provides a detailed framework for interpreting and integrating topical studies of that fault system. Our geologic map integrates more than two decades of intermittent geologic mapping and related investigations by the authors in this part of the Virginia Coastal Plain. Earlier mapping in the Piedmont by Pavlides (1995) has been revised by additional detailed mapping in selected areas, particularly near Abel Lake and Smith Lake, and by field evaluation of selected contact relations.

GEOMORPHIC SETTING The Stafford quadrangle encompasses parts of two very different geologic provinces—the Appalachian Piedmont to the west and north and the Atlantic Coastal Plain to the east and south. The Piedmont province consists of steeply dipping, metamorphosed sedimentary, volcanic, and intrusive rocks having a pronounced northeast-trending structural grain. Fresh, unweathered rock, exposed in the deeper stream valleys and on the steeper slopes, is commonly hard and resistant to erosion. The gentler slopes and ridge tops are covered by a mantle of soft decomposed rock (saprolite), as much as 40 feet (ft) (12 meters (m)) thick, derived by weathering of the underlying crystalline rock. The surface of the crystalline rock is irregular but dips eastward at low angles beneath the much younger, unconsolidated Coastal Plain

In the Stafford quadrangle area, as elsewhere in the innermost Virginia Coastal Plain, differential erosion along the contact between the soft, easily eroded Coastal Plain strata to the east and the resistant Piedmont rock to the west commonly causes falls or rapids to form at or just west of the boundary between the two terranes. The geographic "Fall Line," a term applied here to the imaginary line connecting the falls or rapids in successive streams crossing the Piedmont-Coastal Plain boundary, is the upstream limit of navigability on major rivers. Thus, it was commonly the site of important colonial cities such as Richmond and Fredericksburg. In the Stafford quadrangle area, the northeastward-trending geomorphic Fall Zone is the point where the wide, flat-bottomed, alluvium-filled valleys of Aquia Creek, Austin Run, and Accokeek Creek narrow abruptly to V-shaped valleys incised into the Piedmont crystalline rock. In this area and the adjacent Quantico and Fredericksburg quadrangles, the coincidence of the Fall Zone with structures of the Stafford fault system indicates that the Fall Zone is tectonically controlled (Mixon and Newell, 1977).

The Piedmont province in the Stafford map area consists of Neoproterozoic(?) to early Paleozoic metamorphosed sedimentary, volcanic, and intrusive rocks. The rock units, age constraints, geologic history, and various tectonic interpretations have been described in reports by Pavlides (1976, 1980, 1981, 1989, 1990, 1995, 2000) and

PIEDMONT ROCKS

The Lunga Reservoir Formation (OI) in the northern part of the quadrangle is part of a mélange terrane (Potomac composite terrane of Horton and others, 1991), and it contains clasts interpreted by Pavlides (1989) to be derived from the Chopawamsic Formation (Oc and Ocf). Metavolcanic rocks of the Chopawamsic Formation (Oc and Ocf; Southwick and others, 1971) and plutonic rocks of the Garrisonville Mafic Complex (OZgm) are interpreted, on the basis of geochemistry (Pavlides, 1981, 1995), as parts of a volcanic-arc terrane (Chopawamsic terrane of Horton and others, 1989, 1991). The Chopawamsic Formation was formerly inferred to be Cambrian (Pavlides, 1981, 2000) but more recently has been dated as Ordovician (Horton and others, 1998). The Chopawamsic Formation is thought to be unconformably overlain by the Quantico Formation (Oq, Oqv), which contains Ordovician fossils (Pavlides and others, 1980). The fossil age is corroborated by a U-Pb zircon age of 451±6 Ma (Horton and others, 1998). The Quantico Formation has been widely interpreted as part of a late Taconic successor basin (Horton and others, 1989; Pavlides, 1989, 1990, 2000). Because the Quantico and Chopawamsic Formations are similar in age, a re-evaluation of their relations and their significance with respect to an Ordovician volcanic arc that was previously unrecognized in the central Appalachian Piedmont should be undertaken Rocks of igneous intrusive origin in the Stafford quadrangle are variably

metamorphosed. They include tonalitic to dioritic and granodioritic gneiss of the Potomac Creek pluton (PzZgn), amphibolite and hornblendite of the Garrisonville Mafic Complex (OZgm), amphibole metagabbro (Ogb) west of Mountain View, metatonalite of the Richland Run pluton (Opg), and muscovite-biotite granite (SOgr). The muscovite-biotite granite (SOgr) is interpreted to crosscut rocks of the Garrisonville Mafic Complex and Richland Run pluton on the basis of map relations. The metamorphic zones in this quadrangle have not been mapped in detail. In general, pelitic mineral assemblages in the Quantico Formation, and mafic mineral assemblages in the Chopawamsic Formation, Garrisonville Mafic Complex, and amphibole metagabbro show an increase in metamorphic grade from the northeast to the southwest (Pavlides, 2000). Schist of the Quantico Formation contains minor garnet in the northern part of the quadrangle and staurolite + garnet in the southern part, where kyanite + quartz veins also are locally present (Pavlides, 1995). 40Ar/39Ar dating of hornblendes along the same metamorphic gradient near Fredericksburg, Va., indicates that this metamorphism was a late Paleozoic (Alleghanian) event (Sutter and others, 1985).

STRUCTURES OF THE PIEDMONT Folds and Minor Structures An overview of the structural geology, including foliations, lineations, and small folds, as well as regional folds and faults, is provided by Pavlides (1995, 2000). The

north-northeast-trending Quantico synclinorium is cored by the Quantico Formation and is well defined across most of the Fredericksburg 30'x60' quadrangle (Mixon and others, 2000). In the Stafford 7.5-min quadrangle, however, the outcrop of the Quantico Formation is relatively narrow and contains a series of alternating synforms and antiforms rather than a single synformal axis. The other folds shown on this map do not appear to be major regional structures.

Piedmont Faults

nature of that contact in this quadrangle is undetermined because of limited exposure.

1995), yet our more recent field mapping suggests that the fault terminates about 2

1970; Pavlides, 1995). Structural analysis (Bailey and others, 2003) indicates that the

Spotsylvania fault is a transpressional, high-strain zone characterized by dextral strike-

slip and a contractional component, rather than a thrust fault as inferred on earlier

maps (for example, Mixon and others, 2000). Pavlides (2000) suggested that the Fall

Hill fault of the Stafford fault system (discussed below) may be rooted in a northeast-

**COASTAL PLAIN DEPOSITS** 

The Coastal Plain deposits in the Stafford map area consist mainly of Lower

Cretaceous and lower and upper Tertiary sands, silts, and gravels with lesser amounts

of clay and limestone. Except for compaction and dehydration, these mostly unlithified

sediments have been little altered since deposition. The definition and extent of

stratigraphic units, their paleontology and age, environments of deposition, and

geologic history have been described in reports by Mixon and others (1972, 1989a,b,

1994, 2000); Reinhardt and others (1980a,b); Ward (1985); and Weems and others

By far the greater volume of sediment is the dominantly crossbedded, feldspathic

sands and sandstones assignable to the Potomac Formation (Kp). Coarse channel-lag

and channel-bar deposits and clay plugs indicate deposition in coalescing streams.

Well-preserved leaves and stems of ferns and cycads, and silicified trunks of large

conifers indicate abundant vegetation. About 20 to 30 mi (35-40 km) east of the

Stafford quadrangle, where the Lower Cretaceous sedimentary basin is much deeper,

fluvial-deltaic deposits intertongue with fossiliferous marine facies of the Cretaceous

The continental deposits of the Potomac Formation are overlain with great

erosional unconformity by sediments of the Pamunkey Group, which consist mainly of

thick-bedded or massive glauconitic quartz sand of marine origin. In the eastern part

of the quadrangle, mollusks are concentrated in thick to very thick beds suggesting

open-shelf depositional environments. In western updip areas, however, black heavy-

mineral laminations, burrows of the Ophiomorpha nodosa type, and small bars

composed of clean, well-sorted sand become more common upward in the

and clayey, interbedded with thick- to very thick bedded, diatomaceous silty clay and

clayey silt. Unit is dark olive gray and greenish gray and commonly contains fish teeth

and scales, bones of marine vertebrates including whales, poorly to well-preserved

diatom floras, and dinocysts. Dinoflagellate diversity and composition reflect a shallow-

STRUCTURES OF THE COASTAL PLAIN

Stafford Fault System

echelon, northeast-striking, high-angle reverse or vertical faults extending from

northern Spotsylvania County, Virginia, northeastward along the inner edge of the

Coastal Plain for 42 mi (68 km) to Newington in southern Fairfax County, Virginia

(see Mixon and others, 2000; Davis and others, 2002). The dominantly

compressional faulting involves both the ancient crystalline rocks of the easternmost

Piedmont and the overlying, much younger sedimentary formations of the Virginia

Coastal Plain (Mixon and Newell, 1977, 1982; Seiders and Mixon, 1981). The few

outcrops of the faults commonly show steeply northwest-dipping to vertical fault

planes along which the Piedmont metamorphic rocks are upthrown at high angles

over unconsolidated Lower Cretaceous sands of the Potomac Formation (Kp).

Although vertical displacement of strata by individual faults is moderate (20-200 ft

(6–61 m)), the Stafford faults appreciably affect the present distribution and thickness

of Coastal Plain formations. For example, the relatively downthrown, southeastern

side of northeast-trending faults preserves thicker and more complete stratigraphic

sections (fig. 1). On the northwestern side of the faults, the Coastal Plain formations

are thinner or absent because of partial or complete truncation by younger

In the Stafford map area, the Stafford fault system includes three main mappable

structures: the Dumfries fault zone, the Fall Hill fault, and the Brooke fault zone (see

map and fig. 1). Major mappable structures in adjacent areas include the above named

faults, the Tank Creek fault in the Widewater quadrangle, and the Hazel Run fault in

the city of Fredericksburg (fig. 1). These faults were first recognized during mapping of

the inner Coastal Plain in Prince William and Stafford Counties, Virginia (Mixon and

others, 1972; Mixon and Newell, 1977; Mixon and Powars, 1984). Subsequently,

studies of the nature and timing of deformation of the Stafford fault zone have been

stations (Potomac Electric Power Company, 1976; Mixon and others, 1992).

made to help assess earthquake risk with regard to safe siting of nuclear generating

dumfries fault zone.—The Dumfries fault zone, the northwesternmost structure of

he Stafford fault system, has been mapped from Newington in southern Fairfax

County, Virginia, southwestward along the Fall Zone for about 28 mi (45 km) to the

vicinity of Abel Lake Reservoir, southwest of Stafford. The Dumfries fault zone was

The Stafford quadrangle is the type area of the Stafford fault system, a series of en

shelf, nearshore environment with a fair amount of nutrients available.

The Calvert Formation (Tc) is chiefly fine to very fine quartzose sand, variably silty

trending splay of the Spotsylvania fault zone.

(Reinhardt and others, 1980a).

Quantico quadrangle, the contour lineament coincides with the Fall Zone and, commonly, with the head of tidewater in each of the major, eastward-flowing streams. Chopawamsic thrust fault.—The Chopawamsic fault is interpreted to be an early The abruptness of the oversteepened gradient and the doubling in thickness of the Paleozoic thrust fault that emplaced the Chopawamsic volcanic-arc terrane onto the Potomac Formation southeastward across the lineament indicates faulting of both the mélange terrane of the Mine Run Complex (Pavlides, 1989, 2000). This map follows crystalline basement rock and the overlying Coastal Plain strata. Pavlides' (1990, 1995) interpretation of the contact between the Garrisonville Mafic The Dumfries structure is best exposed in the central part of the Stafford map area Complex and the Lunga Reservoir Formation as a segment of this thrust, although the where slate, phyllite, and schist of the Upper Ordovician Quantico Formation are in fault contact with the more easily eroded sand and gravel of the Lower Cretaceous Long Branch fault zone.—The Long Branch fault zone defines a northeast-striking Potomac Formation. In this area, differential erosion along the fault contact has boundary between the Quantico Formation to the southeast and the Chopawamsic formed a 5-mi (8-km)-long, east-facing fault-line scarp (see map). To better understand Formation to the northwest and extends from the southern edge of the adjacent structural relations, a trench (fig. 2) was excavated across the fault trace about 2 mi (3 Storck quadrangle to the central part of this map as shown by Mixon and others km) northwest of Stafford. The 40-ft (12-m)-long continuous exposure shows that at (2000). The fault is portrayed on this map as a thrust, following Pavlides (1990, this locality (see map) the main structure is a high-angle reverse fault striking N. 59° E. and dipping 68° NW. As is commonly the case with reverse faults of the Stafford mi (3 km) northwest of Stafford. Pavlides (2000) had suggested that the linear trace system, the strike of this fault is at a considerable angle to the more northerly N. 35° E. may be a consequence of late strike-slip movement. These hypotheses have not yet trend of the structure-contour lineament delineating the Dumfries fault zone. Thus, we been tested by kinematic studies of the associated mylonitic fabrics. The mylonitic infer that the fault zone is a series of en echelon and interconnecting faults that strike more easterly than the main structure—a pattern suggesting a dextral strike-slip component of movement

first delineated near the town of Dumfries in the Quantico quadrangle, which is

fabrics extend farther northeastward within the Quantico Formation, where they gradually diminish as strain apparently became less focused and better distributed through that unit. Mylonitic fabrics were not observed where the Quantico-The upthrown Quantico Formation exposed at the western end of the trench Chopawamsic contact can be located on the shore of Smith Lake in the northern part consists of faulted and foliated, gray to black phyllite and slate containing quartz pods. of the map area, and there is no evidence for faulting along the contact in that area. A gouge zone, 8 to 18 in (20–45 cm) wide, consists mainly of clayey material derived North of the Stafford quadrangle, the contact between the Quantico and from the Quantico. Some striations plunge 65° N. in the plane of the fault. Others Chopawamsic Formations is generally not mapped as a fault (Mixon and others, plunge directly downdip. The variation in plunge of these striations suggests that 1972; Pavlides and others, 1980; Seiders and Mixon, 1981), although mylonitic movements on the fault were right lateral oblique as well as dip slip (Newell and fabrics approximately along strike have been described by Heimgartner (1995) and others, 1976). Across the main fault at this locality, vertical separation of the confirmed by J.W. Horton, Jr. (unpub. data) near the Occoquan River. unconformable contact between the Quantico and Potomac Formations is 115 ft (35 Accokeek fault.—The Accokeek fault, a northwest-striking tear fault shown on m) as indicated by augering and detailed field mapping. earlier maps (Pavlides, 1995, 2000), is not shown on this map because no evidence Trench exposures of the downthrown fault block consist of coarse to very coarse, was found to support its existence. The Accokeek fault was inferred by Pavlides to trough-crossbedded, feldspathic quartz sand of the Potomac Formation. These strata explain the northern termination of the Long Branch fault zone and a southwestward are cut by several westward-dipping subsidiary high-angle reverse faults that closely increase in metamorphic grade within the Quantico Formation. Our reassessment of parallel the main Dumfries fault. Also, numerous small normal faults, down to the the evidence indicates that the Accokeek fault is not necessary to explain the first west, truncate earlier reverse faults and may have resulted from relaxation of appearance of staurolite or kyanite in the Quantico Formation or the northern end of compressional stress following reverse faulting. Fault surfaces of the subsidiary reverse the Long Branch fault zone as presently mapped. faults are commonly marked by thin, light-gray to white clay smears probably derived Spotsylvania fault zone.—The Spotsylvania fault zone, a major feature of the from shearing of weathered feldspar. Piedmont to the south, may be concealed beneath Coastal Plain strata in the eastern Fall Hill fault.—The Fall Hill structure is a narrow zone of dominantly high-angle part of the quadrangle as projected on the basis of aeromagnetic data (Neuschel,

reverse faults mapped from the Stafford, Va., area southwestward for about 11 mi (18 km) to the edge of the Piedmont in northeastern Spotsylvania County. The Fall Hill fault is named for exposures on Fall Hill (see Fredericksburg 7.5-min quadrangle), a 250-ft (76-m)-high ridge of Piedmont crystalline rock, capped by thin Coastal Plain deposits and overlooking the Rappahannock River. Where the fault zone crosses the Rappahannock River just upstream from Laucks Island, it causes a series of rapids, which constitutes the Fall Zone on the Rappahannock. The Fall Hill fault was formerly well exposed in low roadcuts along Fall Hill Avenue in Fredericksburg (Mixon and Newell, 1978, 1982; Mixon and others, 2000) but is now obscured by subsequent widening of the road. At this locality, near the top of the hill, coarse-grained biotite gneiss of the Po River Metamorphic Suite is thrust at a high angle over sand of the Lower Cretaceous Potomac Formation. Offset of high-level Rappahannock River terrace deposits of probable Pliocene age at this site indicates some fault movement in latest Tertiary or Quaternary time.

Excellent trench exposures of the Fall Hill fault were available for a short time at the Falls Run northwest of Falmouth, Va., about 1.5 mi (2.4 km) northeastward along strike from the Rappahannock River. Here, studies conducted by the Dames and Moore engineering firm for Potomac Electric Power Company showed that the Fall Hill structure is a 30-ft (9-m)-wide zone of shearing that includes both vertical faults and steeply northwest-dipping high-angle reverse faults (fig. 3) (Mixon and others, 2000). In the Falmouth area, the main Fall Hill structure strikes about N. 35° E., but the strike of individual faults exposed by the trenching ranges from due north to N. 57° E. (Potomac Electric Power Company, 1976, pl. 9). The trench studies provided the first clearcut evidence that displacement of lower Tertiary strata (Aquia Formation (Ta) of upper Paleocene age) took place, at least in part, as the result of faulting rather than simple flexuring as had been suggested by some workers. The Fall Hill fault is not well exposed along its northward projection through the Stafford quadrangle area. However, mapping the top of the Potomac Formation

(which is equivalent to contouring the base of the directly overlying Aquia Formation of upper Paleocene age) has shown that the fault extends at least as far north as Coal Landing on Aquia Creek. Structure contours on the base of the Aquia Formation in both the Stafford and the Fredericksburg quadrangles indicate a fairly consistent 40 to offset of the crystalline rock surface between U.S. Geological Survey auger holes nos. 5 and 6, which are about 1.2 mi (1.9 km) south of Stafford and east of U.S. Highway 1, are similar to displacements elsewhere along the Fall Hill fault. Brooke fault zone.—The Brooke fault zone was originally mapped in reconnaissance as the Brooke monocline (Mixon and Newell, 1977). Subsequently, detailed mapping disclosed a 1-mi (1.6-km)-wide zone of en echelon faults extending from the vicinity of Massaponax in Spotsylvania County northeastward for about 25 mi (40 km) to the Quantico Marine Corps Base in eastern Prince William County, Virginia (see Mixon and others, 2000). At Quantico, the Brooke fault zone projects northeastward beneath the upper Potomac River estuary toward Alexandria, Va., and Washington, D.C. The position of this northeasterly reach of the Potomac River is thought to be controlled by the relative down-to-the-east displacement of the Coastal Plain strata along the Brooke fault zone and other fault structures along the northern part of the Stafford fault system (Seiders and Mixon, 1981, their fig. 1). In the Stafford map area and the adjacent Widewater and Fredericksburg guadrangle areas, the Brooke fault zone includes two parallel fault strands. These faults were mapped by structure contouring control points on the top of the Lower Cretaceous Potomac Formation. Vertical offset of the Potomac-Aquia unconformity across individual faults is commonly 35 to 45 ft (11-14 m). Cumulative offset of the top of the Potomac Formation across the entire Brooke fault zone is as much as 100

Although fault displacements are small, these structures appreciably affect the distribution and thickness of Coastal Plain formations. For example, between Aquia Creek and Potomac Creek, the southeasternmost fault of the Brooke fault zone (see map) marks the present-day updip limit of the Marlboro Clay (Tmc) and the Nanjemoy Formation (Tn) (fig. 1). On the southeastern, downthrown side of the fault, the lower and middle Miocene Calvert Formation unconformably overlies the lower Eocene Nanjemoy Formation. On the northwestern, upthrown side of the fault, the Miocene beds directly overlie the upper Paleocene Aquia Formation. Thus, the Marlboro and the Nanjemoy beds were eroded from the upthrown side of the fault during middle Eocene to early Miocene time. These relations indicate a middle Tertiary episode of deformation in this region.

ECONOMIC GEOLOGY The Stafford map area is important economically because of its abundant water resources including two freshwater reservoirs (Smith Lake and Abel Lake) that supply much of the drinking water for Stafford County. The subsurface water supply depends mainly on water wells drilled into the Potomac aquifer which is recharged, in part, through the extensive, sandy outcrop belt of the Potomac Formation (see Mixon and others, 2000). Fine-grained to coarse-grained intrusive rock of the Garrisonville Mafic Complex

adjacent to the northeast of the Stafford map area. There, detailed mapping of the source of crushed stone used for road metal and other construction purposes. Rocks top of the Piedmont crystalline rock showed an oversteepened, southeast-dipping of the Chopawamsic Formation contain gold and base-metal massive sulfide deposits of submarine volcanic exhalative origin (Pavlides and others, 1982), but no such gradient as a pronounced structure-contour lineament trending southwestward through Dumfries, Triangle, and Boswells Store and northeastward toward deposits have been mined in this quadrangle. Woodbridge, Va. (Mixon and others, 1972; Seiders and Mixon, 1981). In the In the early 19th century, building stone from sandstone of the Lower Cretaceous Potomac Formation was obtained from small quarries on Government Island at the head of tidewater on Aquia Creek. The stone was used originally in construction of part of the U.S. Capitol building and part of Aquia Church, which is about 2 mi (3 km) north of Stafford along U.S. Highway 1. Rapid weathering and structural failure of stone used in the Capitol building have led to the removal of the stone.

Table 1.—Floral list compiled for Potomac Formation from shallow excavation about 2 mi (3 km) south-southwest of Stafford County Courthouse, in the southwest quadrant at the intersection of Interstate I-95 and Va. Route 628. The location of hese flora is indicated by the  $\diamondsuit^{\mathsf{MF}}$  symbol on the map. [Plant fossil identifications by L.J. Hickey, written commun., 2003]

(OZgm), quarried about 2 mi (3 km) west of the town of Garrisonville, is an abundant

SCIENTIFIC INVESTIGATIONS MAP 2841

Angiopteridium ovatum Fontaine Onychiopsis goeppertii (Schenk) Berry

Dioonites buchianus (Ettingshausen) Bornemann Naegiopsis zaminoides Fontaine Nilsonia densinerve (Fontaine) Berry Scleropteris elliptica Fontaine

Sphenolepidium sp. Ficophyllum crassinerve Fontaine

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**EXPLANATION** 

Tps Pliocene sand and gravel Tms Miocene sand and gravel

Ta Aquia Formation (upper Paleocene) Kp Potomac Formation (Lower Cretaceous) PzZp Piedmont rocks (Neoproterozoic and lower Paleozoic) Tc Calvert Formation (lower and middle Miocene) **Fault**—Dashed where inferred; dotted where concealed

Tn Nanjemoy Formation (lower Eocene) Tmc Marlboro Clay (upper Paleocene)

> Figure 1.—Variation in stratigraphic section across structures of Stafford fault system as observed in outcrop. Down-to-the-coast displacement of Coastal Plain beds by high-angle reverse faults preserves thicker and more complete sections on the southeastern side of structures. Conversely, on the relatively upthrown, northwestern side of faults, westward onlap by marine formations (Aquia and Calvert) has resulted in sharp truncation of older strata. Southwest-northeast differences in stratigraphic section reflect varying amounts of displacement along structural strike and relief on unconformities. Stafford quadrangle is shown in red.



scale 1:24,000.